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Evaluation of Surface Roughness and Cutting Temperature of EN31 Steel with Varying MQSL Parameters

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Abstract. In the present-day manufacturing industry, achieving machining accuracy, high production rate, high material removal rate and increasing tool cutting life is becoming more vital and a particularly difficult task. Machining of hard material imposes a lot of challenges, mainly high temperature generation between tool-workpiece interface. Enormous heat generation adversely affects surface roughness, tool life, dimensional quality of the workpiece and deteriorates the tool life significantly. The use of proper lubrication in machining processes is critically important to modify the conditions of contact area by effective control over frictional interaction which should ensure change in tool-chip interface and machining mechanics. In the present work an experimental investigation was carried out on various MQSL parameters on surface roughness and tool temperature in turning EN 31 steel and the results are compared with dry turning. In order to apply lubricants at shearing interface (chip flow at the rake face of the tool) high velocity MQSL set-up is fabricated. The present work has achieved significant results and helped in concluding the influence of lubricant parameters of MQSL in turning process.

1. Introduction

Since the past two decades the practicality of conventional lubrication techniques like flood lubrication are being reconsidered due to the involvement of socio, economic and ecological aspects. There is an emerging need for green and preservative manufacturing. The recycling of the lubricant being difficult and high-priced, [1] concludes that in flood lubrication the total liquid costs (including amount spent on refrigeration) amounts for 17% of the total production cost. The National Institute for Occupational Safety and Health (NIOSH) assesses that about 1.2 million workers are involved in cutting operations and other metalworking operations are exposed to metalworking fluids every year [2]. Exposure of skin to such liquids represent health related concerns, as does the inhalation of the evaporated and other aerosol particles causes pulmonary problems and several types of cancer [3,4]. This makes the use of cutting fluids an issue based on both environmental and health concerns both long-term and short-term consequences.
However, the global demand for productivity and better quality products is constantly increasing by the day. This paired along with the rise of competition in the industrial sector and strong requirement to reduce the cost, the need for high material removal rate along with stability as well as long life of

cutting tool is more than ever. In comparison with conventional cutting, machining with high speeds increases the efficiency, the production rate, the accuracy and the overall quality of the final workpiece. These processes generate excessive cutting temperature zone due to the high velocity and feed rate which often affect the surface roughness. The cutting tool will be softened and the surface roughness of the workpiece will be deteriorated [5]. Roughness plays a vital role in forecasting the performance of the machine members as cracks lead to undesirable effects like corrosion and failure. Surface roughness affects the fitting between mating components, ability to withstand corrosion, flow of liquids along pipes, aesthetic appeal of a product. It has become increasingly important to provide appropriate cutting conditions to achieve better surface finish. The need for better quality machining put together with the downsides of using conventional lubrication make alternative lubrication techniques all the more important [6,7].

MQL on the other hand meets all the aforementioned requirements. As the name suggests, the quantity of applied lubricant is reduced impressively to often 50 ml/hour-500 ml/hour, as compared to the sizable thousands of litres of coolant per hour in conventional flood lubrication. This offers other advantages like dry chips as well as workpiece after machining. A lot of research is being done on dry and near- dry machining recently, and minimum quantity lubrication (MQL) machining in particular has been accepted as a successful semi-dry application because of its environmentally friendly characteristics. MQL has been studied in many machining processes, such as drilling [8], milling [9], turning [10], and grinding. These studies showed that with the proper selection of MQL system and cutting parameters, it is possible to obtain performance comparable or better than that with flood lubrication. Machining of 6061 aluminium alloy with MQL, dry and flooded lubricant conditions by P S Sreejith [11] studied the effect of dry machining, minimum quantity of lubricant (MQL), and flooded coolant conditions with respect to the cutting forces, surface roughness of the machined work-piece and tool wear and found that MQL condition will be a very good alternative to flooded coolant/lubricant conditions. Therefore, it appears that if MQL properly employed can replace the flooded coolant/lubricant environment which is presently employed in most of the cutting/machining applications, thereby not only the machining will be environmental friendly but also will improve the machinability characteristics.

Effect on tool wear A Attanasio [12] worked on the results obtained from turning tests and SEM analysis of tools, at two feed rates and two cutting lengths, using MQL on the rake and flank of the tool. The results obtained portrays that when MQL is applied to the tool rake, tool life is generally no different from dry conditions, but MQL applied to the tool flank can increase tool life. Experimental measurement and modelling of surface roughness in turning with CaF2 solid lubricant assisted minimum quantity lubrication by Mayurkumar [13] made correlation between the cutting parameters and measured surface roughness in wet and solid lubricant assisted machining and indicate that surface roughness is affected by feed, depth of cut followed by cutting speed. These outcomes can be used by the machining industry to use the best combination of parameters affecting surface roughness with the MQSL approach. The performance of graphite and boric acid powder blended in SAE 40 oil has been assessed in turning by Krishna and Rao (2008)[14]. The workpiece chose was made of EN8 steel and the tool was cemented carbide. Graphite and boric acid powder in various extents by weight, blended in with SAE 40 oil. The results concluded that solid lubricant assisted machining better than a dry and wet machining environment and 20% of boric acid in SAE 40 oil assisted machining, providing better results. Parametric investigation of turning process on en-31 steel by L B Abhanga [10] deals with study the effect of machining parameters such as cutting speed, feed rate, depth of cut, tool nose radius and lubricant on surface roughness while turning En-31 steel. Concluded that the surface roughness increases with increase in feed rate and depth of cut but surface roughness decreases with increase in cutting speed and tool nose radius respectively.

Performance assessment of MQSL: Minimum quantity solid lubrication during turning of Inconel 718 by A Marques, [15] studied the effect of applying solid lubricant (molybdenum disulphide and graphite) mixed with oil, during turning of Inconel 718 using cemented carbide tools in which the concentration of the solid lubricant in the fluid and the flow rate of the mixture were varied to analyse the main output parameters such as surface roughness, cutting forces and tool life and concluded that this to be a cost-effective and environmental-friendly lubrication technique than flood coolant and sprayed oil with or without graphite to retard all types of damaging processes and to improve machinability characteristics of Inconel 718.

The above-mentioned studies indicate that the application of solid lubricant–assisted machining is a new technique to control the machining zone temperature without polluting the environment and the great potential of using solid lubricants for low-cost machining under different conditions.

A lot of parametric studies have been done by varying MQSL cutting parameters in turning but there is very little literature available when it comes to MQSL parameters. The main goal of this work is to carry out an experimental investigation on various MQSL parameters (position, distance, feed rate) on surface roughness and tool temperature and compare the results with MQL and dry turning of EN31 steel. The summarized effects and results for various MQL parameters are shown in Table 1.

Table 1. Literature review for MQL parameters.

S. No	Author	Type of lubrication	Parameters	Effect on	Results obtained
1	A.Marques, Suresh Kumar, AR Machado	MQL(Molybdenum disulphide and graphite)	Concentration of solid lubricant and flow rate	Surface roughness, cutting forces and tool life	Cost effective and environment friendly than flood lubrication
2	Mayur Kumar A, Kaushik M Patel	MQL (CaF_2 + SAE 40) Cutting fluid	Feed, depth of cut and cutting speed	Surface roughness	Surface roughness is affected by all 3 parameters
3	Rakesh Kumar Gunda, Narala Suresh Reddy	HP- MQL	High speed machining conditions	Tool wear, surface roughness	HP-MQSL at small and constant flow allows better penetration
4	A Attanasio M.Gelfi	MQL(tool wear effects)	Only 2 feed rates and 2 cutting lengths fixed	MQL on tool rake and tool flank	On tool rake, no difference but on tool flank , life increases
5	Karnik, Paulo Davi M, V.N. Gaitonde	Optimum MQL	Cutting speed, feed rate	Surface roughness and specific cutting force	MQL=200 ml/he, cutting speed 200m/min, Feed rate=0.05min/rev
6	P.S. Sreejith	MQL, dry and flood lubrication	High speed machining conditions	Cutting force and surface roughness	MQL is better when compared to wet and dry

2. Experimental Setup and Procedure

The experimental setup (shown in Figure 1) consists of an air-compressor which is connected to a T-joint to equally divide the air flow into the nozzle and the hydraulic reservoir. The T-joint also houses an air flow sensor which is connected to a node MCU. The instantaneous and average flow rate is displayed on a computer connected to the node MCU. A 1.5l air-tight container made with reinforced plastic is used as the reservoir and it has one inlet port for high pressure air, a pipe which is dipped till the bottom end of the reservoir and an outlet port which is connected to this pipe. When air is pumped into the container, it is pressurised and the lubricant liquid is forced to exit from the outlet port with high pressure. This lubricant outlet is connected to a flow control valve to control the amount of fluid flow per unit time and the other end of the flow control valve is connected to the nozzle. The other end of the T-joint is connected to the 2nd inlet port of the nozzle. The nozzle is fitted on a nozzle stand using a T-clamp which is fixed to the movable carriage so that the nozzle will move with the tool. The nozzle stand is moved to perfectly place the nozzle end near the machining zone perpendicular to the tool. The EN31 steel which is to be machined is placed in the 3-jaw chuck in the head stock while the carbide tip tool is fitted into the tool post. IR temperature sensor is used to measure the instantaneous temperature of the machining zone and the tool. The air compressor is turned on and it maintains the air pressure at 4 bar and the flow control valve is set at 182 ml/hour. The spindle is made to rotate at

598 RPM so that the velocity of cut is maintained at 122 m/min. A depth of cut given is 0.5mm is given. Feed is given manually to the tool and turning operation is performed on the EN31 steel workpiece.

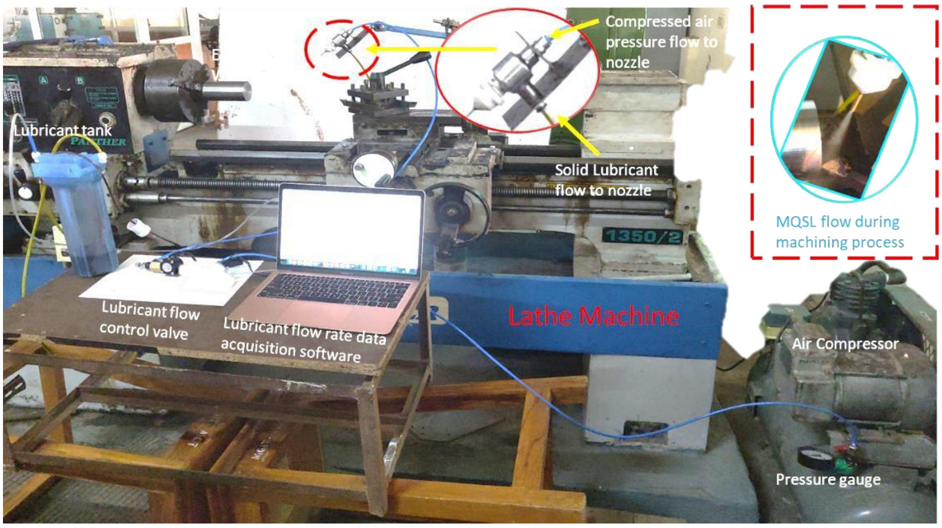

Figure 1. MQSL set-up.

3. Result and Discussions

In EN31 steel turning process employing MoS_2 mixed with SAE-20W40 base lubricating oil as a minimum quantity solid lubricant, is a possible environmentally friendly, alternative for effective control of chip-tool interface temperature. Hence in the present evaluation, varying concentrations of MoS_2 with SAE-20W40 base oil has been used as a minimum quantity solid lubricant to provide the proper lubrication and reduce the friction between chip-tool interface and thereby reducing heat generation between the chip-tool and tool work piece interface.

3.1 Surface Roughness:

Surface roughness (Arithmetic Average: Ra): Good surface finish is usually achieved by finishing methods like surface grinding but sometimes it is left to machining. Even if it is to be finally finished by grinding, machining prior to that needs to be done taking into consideration the surface roughness so as to reduce the costs of grinding operation and reduce initial surface defects as far as possible. Built-up edges, feed marks due to irregular feed, irregular deformation of the tool tip are the key factors to avoid. Surface roughness grows sharply in dry machining due to the high rise in temperature and softening of the tip. The MQSL setup succeeded in reducing the surface roughness. Factors of the MQSL system i.e., air pressure, nozzle distance, flow rate of the lubricant, concentration of MoS_2 in the lubricant base oil were varied and results were observed. Due to increase in the air pressure the chips are removed as soon as the turning operation is done resulting in the better surface finish and it helps in avoiding the formation of built up edge resulting in low surface roughness. As the nozzle distance decreases it was observed that more concentrated application of lubricant and air due to which surface roughness is improved. Flow rate of the lubricant is maintained in optimum conditions ranging from 100-300 ml per hour to obtain lower surface roughness. During machining under such high cutting temperature, the solid lubricant forms a thin film on rake face of the tool. The Ra is calculated as the roughness average of a surface measured microscopic peaks and valleys, it is one of the most effective surface roughness measures commonly adapted in general engineering practice and it gives a good general description of the height variations in the surface. Figure 2 shows the average results of Ra (surface roughness) obtained under different parameters. It has been observed from Figure 2 that the Ra was not affected significantly under the considered parameters after analysing the standard deviation bars. However, based on the average values, the surface finish is better under these conditions. The average values of Ra when using different concentrations of MoS_2 in the base oil were

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the lowest among the other tested parameters. The addition of MoS_2 with MQL yields lower surface roughness. A broad comparison of the surface roughness values in all the three conditions was also documented.

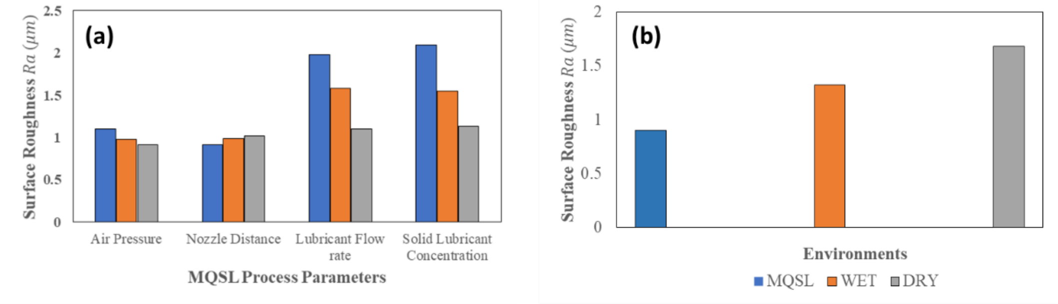

Figure 2. (a) Surface rough measurement during turning under various MQSL process parameters (b) Surface roughness measurement during turning EN31 steel under MQSL, Wet, Dry environment condition.

3.2 Cutting Temperature

The main heat generation zones while machining are, (i) initial zone because of shear and plastic deformation, (ii) chip–tool interface due to deformation and sliding and (iii) work–tool interfaces due to friction. Among those sources substantial effect is done by both the chip-tool and the work-tool interface which mainly influence the manner of chip formation, cutting forces and tool life. In the conducted experiments, efforts were made to decrease the effective cutting temperature. The cutting temperature as shown in Figure 3 taking 3 different values of all input parameters. Conventional flood lubrication fails to provide the required efficiency at both the important interfaces, the chips are still continuous to an extent and these hefty chips make contact with the tool rake surface. On the other hand, it was observed that the MQSL setup aided reduction of the average cutting temperature by about 20–25% depending upon the levels of the process parameters. In the system that was developed the air pressure increases the air and passes through the nozzle and then through the orifice where there is a huge pressure difference because of which the high pressure air condenses due to Joule Thompson effect and the condensed air thus reduces the cutting temperature on a large scale. The factors of the MQSL system like air pressure, nozzle distance, flow rate of the lubricant, concentration of MoS2 in the lubricant base oil were varied. Results helped in concluding that the air pressure has a key role in reducing the cutting temperature. Increase in air pressure also decreases the lubricant particles size and thus resulting in uniform and efficient lubrication. Nozzle distance affects the cutting temperature by varying the area of application, by minimizing the area of application of lubricant, the cooling effect of the lubricant and the condensed air will decrease the heat generated at the cutting interface. Flow rate of the lubricant determines the output amount of lubricant. By lowering the flow rate the temperature also decreased. MoS2 was added in different percentages to the lubricating oil. By varying the concentration of MoS2 in the base oil the thickness of the lubricating film has increased and hence reduce the friction between the work tool interface during turning operation.

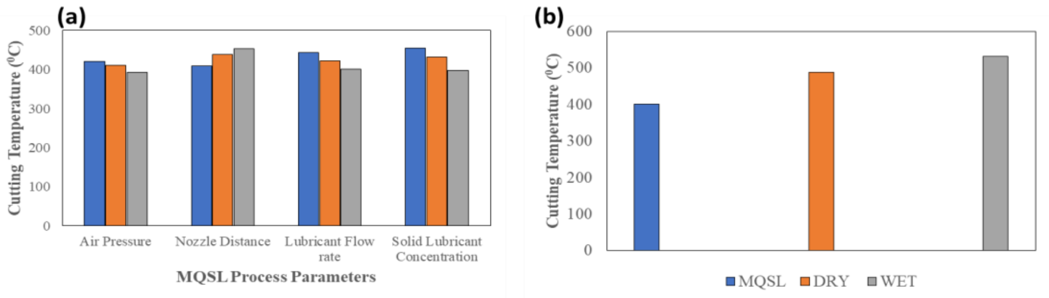

Figure 3. (a) Temperature measurement during turning under various MQSL process parameters (b) Temperature measurement during turning EN31 steel under MQSL, Wet, Dry environment condition.

4. Conclusion

MQSL experimental set-up aiming to improve the overall surface finish; the formation of thin film of lubrication on the rake face of the tool reduces the frictional forces between the tool and chip, which subsequently reduces the temperature developed and prevents the tool wear which further leads to better surface finish. If the fluids are applied precisely to the machining zone, improved results can be expected. Within the selected machining experimental domain, the influence of MQSL in terms of different parameters such as air pressure, nozzle distance, flow rate of the lubricant, concentration of MoS2 in the lubricant base oil, surface roughness of machined surface has been demonstrated during machining of EN31 steel and MQSL. The results demonstrate that the effectiveness of the use of MQSL in reducing friction and heat generation at work–tool interface and contribute to the decrease in the tool wear. Surface roughness and Cutting temperatures of the machined part showed significant variation in different MQSL parameters.

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